THE VOLCANIC ROCKS OF THE ANDES.

THROUGH the excellent work of Dr. Richard Küch,[1] who has recently published the results of his investigation of the rocks collected by Reiss and Stübel in Colombia, we are put in possession of some important conclusions regarding the character of all the volcanic lavas of the South American Andes. Most of these conclusions are pointed out by Dr. Küch in the work cited; to these the present writer wishes to add a few not heretofore noted.

In order to appreciate the value of Küch's work, it should be observed that it was carried on upon the very extensive material collected by Reiss and Stübel during a prolonged exploration of the high mountainous regions of South America, in which they visited Colombia, Ecuador, Bolivia, Peru and Chili and brought away with them 18,000 specimens. In some places as many as 800 were collected, in others much fewer; for, as Reiss observes in the introduction to the volume upon Colombia, many of the mountains are well nigh inaccessible, their bases being covered with dense forest, and their summits hidden beneath snow and glaciers, and shrouded with clouds the greater part of the year. This is equally true of the Cordilleras farther south, so that the exploration of the region is attended with great difficulties. And while it is not claimed that the collections are complete, they must certainly be taken as representatives of the whole of the Andes.

The volcanoes of Colombia chiefly occur along the crest of the central range, rising above crystalline schists, and eruptive masses in the Cretaceous formation, whose upturned strata compose the ranges east and west of the central Cordillera. Heretofore, with few exceptions, the volcanic rocks examined have

[1] W. Reiss and A. Stübel: Reisen in Süd-Amerika. Geologische Studien in der Republik Colombia, I. Petrographie. 1. Die Vulkanischen Gesteine bearbeitet von Richard Küch. Berlin, 1892.

been from the Andes south of the equator. In the present instance our knowledge of them is extended to the most northern end of the great Cordilleran system.

A critical review of all previous work upon the lavas of the Andes, and its comparison with that by himself on the lavas of Colombia, and with a preliminary study of the collections by Reiss and Stübel from Ecuador, led Küch to the conclusion that essentially the same petrographical relations exist at all the volcanoes of the Andes.

With few exceptions all of these recent volcanic lavas of which we have any knowledge, are andesites and dacites, that is, rocks whose essential constituents are soda-lime-feldspar and one or more of the minerals: pyroxene, hornblende and biotite, with which is associated quartz, in the case of dacite. Recent eruptive rocks whose mineral composition falls outside of this group appear to be of rare occurrence, and are rocks closely related to andesite and dacite in composition, namely: quartz-trachyte or rhyolite on the one hand, and basalt on the other. In two instances rocks described as trachyte and quartz-trachyte by Stelzner are shown by Küch to be more properly dacite.

The known occurrences of true basalt are few, the most basic rocks being more closely related to pyroxene-andesite than to basalt, according to Küch's interpretation. Dacite, though seldom mentioned by previous investigators, is of very frequent occurrence judging from the collections by Reiss and Stübel.

The study of such abundant material naturally led Küch to first treat the lavas of Colombia as one general group of intimately connected varieties, without reference to their geographical distribution, for it became evident, as he remarks, that neither a single rock, nor a specially abundant development of any one kind, nor the association of a certain number of different rocks could be considered characteristic of any particular volcano. The same rocks with like multiplicity of development, and the same associations of rocks, repeat themselves in different localities in such a manner that what may seem to be the prevailing or the subordinate varieties in one place are more likely to appear such

because of the greater or less completeness of the material collected, than by reason of their actual scarcity or abundance in nature.

The chief feature of the report consists in the systematic description of the lavas of Colombia based upon their microscopical investigation in conjunction with their chemical analysis. The second part of the report is devoted to a description of the rocks in connection with their geographical distribution. It is to be regretted that the geological relations of the rocks with one another are not furnished at the same time.

The rocks are first discussed from a mineralogical standpoint, their mineral composition and structure being taken as the basis of classification within the general group of extrusive igneous rocks, to which they all belong. They are all embraced within the families of andesite and dacite, as defined by Rosenbusch. They present a chemical series grading from rocks relatively poor in silica and rich in lime and magnesia with sodium considerably in excess of potassium, to those comparatively rich in silica, and poor in lime and magnesia, but with sodium still in excess of potassium. The lower limits approach basalt, and the upper limits border rhyolite.

The same gradual transition exists in the mineralogical composition. At one end are pyroxene-andesites with accessory olivine, the feldspars being rather basic plagioclase. These pass into pyroxene-andesites without olivine, and into hornblende-pyroxene-andesites, and hornblende-andesites, and with increasing amounts of quartz into dacite, or quartz-andesites. In the dacites the feldspars are: plagioclase, approaching albite, and sanidine; while biotite becomes prominent among the ferromagnesian minerals.

In considering the classification of such a series of rocks, since their mode of occurrence is the same throughout, namely, that of lava streams, Küch finds the grounds of classification to be: chemical composition, mineral composition and structure. Of these, chemical composition is undoubtedly that which under like conditions of solidification controls the mineral and structural

development of the rock. Consequently he concludes that upon purely theoretical grounds a chemical classification would be the most desirable. But from the present condition of our knowledge this would be impracticable.

Moreover, he observes, that while the chemical analysis of an unaltered rock furnishes us with the proportions in which the elements existed in the molten magma, it is very probable that rocks of like chemical composition may have been derived from magmas consisting of quite different silicates (that is, possessing different molecular constitutions). And this he suggests is one of the reasons why eruptive rocks with corresponding analyses can exhibit quite different mineralogical compositions. In a foot note he observes that another cause for this phenomenon may lie in differences in the process of solidification, which may affect the rearrangement of the compounds originally in the magma. To this extent the mineralogical composition is dependent on the genesis of eruptive rocks, which he considers essentially the same as their geological mode of occurrence.

Since we are not in a position to infer the original molecular constitution of a magma from its chemical analysis, he does not consider a chemical basis of classification applicable. Nevertheless he states that a comparison of the chemical composition of the andesitic lavas with their mineralogical composition shows that certain differences of chemical composition go hand in hand with others of mineral development, and with these are also connected modifications of structure.

The mineralogical features are the most pronounced, and are therefore selected as a basis of classification. The first subdivision is based on the presence or absence of quartz, and the groups become andesites and dacites. They are not, however, distinctly separated from one another, being connected by gradual transitions. But this grouping, as a purely mineralogical one, fails, as he himself points out, in cases where quartz has not crystallized, as in certain dacitic glasses.

In the further subdivision of these groups the ferromagnesian minerals are employed as distinguishing characteristics, and the

following divisions are established under andesite: Pyroxene-andesite, hornblende-pyroxene-andesite, and hornblende-andesite. Under dacite: Pyroxene-dacite, pyroxene-hornblende-dacite, biotite-hornblende-dacite. As already remarked, the mineralogical gradation from pyroxene-andesite to biotite-hornblende-dacite is by very gradual transitions. Biotite is most abundant in the most silicious varieties.

The microscopical character and the distribution of the porphyritical minerals and of the groundmass, and the relation between the microstructure of the latter and the composition of the rocks are described in detail, and appear to be identical with those existing in the andesites and dacites of western North America. These descriptions are presented in the most satisfactory manner, but need no special notice except to call attention to the occurrence of microlites of quartz in the form of minute pyramids .003 $^{mm.}$ in diameter, which are an essential component of the glassy groundmasses of numerous dacites. Precisely similar microlites of quartz have been observed by the present writer in certain silicious glasses in the Yellowstone National Park, the descriptions of which have not yet been published.

The chemical composition of the rocks is shown by fifteen complete analyses and ten silica determinations. They range from 54.21 per cent. of silica to 70.22 per cent. The analyses were made from perfectly fresh and unaltered rocks, and the high percentage of water found in some cases, which reaches 3.62 per cent., is referred to the glass base. This is sometimes markedly pearlitic and hydrated. The variations in the proportions of the chemical components throughout the rock series is pointed out, and is correlated with the variations in the mineral constituents.

Attention is called to the fact that a frequent mode of alteration among these lavas leads to the development of opal, and the consequent increase in the silica percentage, so that a determination of the silica in a rock may be misleading unless the rock is known to be unaltered.

Dr. Küch's report is to be commended, not only for its scientific excellencies, but also for the form in which it has been published, and the admirable indices which render its details easily accessible.

The facts brought out by this report lead the present writer to certain conclusions regarding the nature of the volcanic ejections of the South American Andes of the greatest importance, which, however, may be modified as our information becomes more complete. In brief, it appears that the main mass of the lavas of all the volcanoes of the Andes is andesite, of variable composition in all localities. It grades into basic varieties, approaching basalt, in some places, and into acid varieties which are dacites, in others. It is probable that the basic varieties would be classed as basalts by many petrologists, but they would not constitute the more basic forms of basalt. The variability in composition and petrographical characters within these limits is pronounced, and proves the intimate relationship between all of the lavas. The almost universal absence of the most basic and most acid members of the series which occur in other regions, namely, the true basalts and rhyolites, is most significant, and, if established by future investigation, would indicate that volcanic activity in the Andes, which is still in force, had developed, by the differentiation of some magma common to the whole great Cordilleran system, a series of lavas of limited range. This series, though precisely similar to parts of others developed in other regions, especially those of Tertiary age in western North America, is wanting in the extreme forms of differentiation common to the latter—that is, in basic basalt and rhyolite. From this we may infer that the general differentiation of the magma supplying the lavas of the Andes has not reached its final stages, in which great volumes of extremely differentiated material will have been developed. It would seem to be in a much less advanced condition than the magmas supplying the lavas in Central America and Mexico, which are in turn less advanced than those of the United States, where volcanic activity is extinct or at least quiescent.

It is not to be expected that all of the volcanoes of the Andes are in exactly the same phase of differentiation, which they undoubtedly are not, but in a general way they have not progressed beyond the limits of olivine-bearing pyroxine-andesite and dacite, and may be considered as having the basalt and rhyolite phases before them. They thus show themselves as comparatively young, or perhaps middle-aged. It will be observed, however, that rhyolite occurs in small amount in Ecuador, as shown by analyses 14 and 15 in Table II.

The chemical similarity of the magmas of the Andes with those of general occurrence in western North America, which are fairly represented by the volcanic rocks of the Yellowstone National Park, is seen upon constructing a diagram of the molecular variation of the essential constituents in a manner employed by the writer[1] and also by Dakyns and Teall[2] in discussing the differentiation of molten magmas.

In Table I are given the chemical analyses of perfectly fresh rocks from Colombia, published by Dr. Küch. The general molecular character of the magmas is shown by diagram I. In the lowest part of the diagram the molecular variation of all of the essential constituents is represented, that of silica being given by the abscissas, the zero point being some distance to the left. In the middle part of the diagram alumina, soda and potash are separated from the lime, magnesia and iron-oxide, which are given by themselves in the uppermost part of the diagram, in order to avoid the confusion of lines in the lowest part. The iron is represented as ferrous oxide. The character of this diagram is quite similar to that of the diagrams for the rocks from the Yellowstone National Park in the paper on the origin of

[1] Iddings (J. P.). The mineral composition and geological occurrence of certain igneous rocks in the Yellowstone National Park. Bull. Phil. Soc., Washington, 8vo. Washington, 1890. Vol. 11, pp. 191–220.

——. The origin of igneous rocks. Bull. Phil. Soc., Washington. 8vo, Washington, 1892. Vol. 12, pp. 89–214, Pl. 2.

[2] Dakyns (J. R.) and Teall (J. J. H.). On the plutonic rocks of Garabal Hill and Meall Braec. Quart. Journ. Geol. Soc. 8vo. London, 1892, May 2, Vol. 48, part 2, No. 190, pp. 104–120.

TABLE I.

Chemical Analyses of Volcanic Lavas from Colombia.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
SiO_2	56.91	57.24	59.13	60.05	61.04	61.09	61.26	63.36	63.50	63.56	65.39	66.03	67.30	68.41	69.56
	.948	.954	.985	1.000	1.017	1.018	1.021	1.056	1.058	1.059	1.089	1.100	1.121	1.140	1.159
TiO_2				.85	.45	.95				.95					
Al_2O_3	18.18	18.02	17.00	15.59	15.72	15.96	16.15	16.35	15.34	15.43	15.49	14.57	17.55	16.08	15.65
	.178	.176	.166	.152	.154	.156	.158	.160	.150	.151	.151	.142	.172	.156	.153
Fe_2O_3	4.65	3.46	7.03	6.95	5.03	4.29	4.39	2.12	3.22	3.02	2.80	2.57	1.47	2.12	1.24
	.029	.021		.043	.031	.026	.027	.013	.020	.018	.017	.016	.009	.013	.007
FeO	3.61	4.13		.65	2.15	2.03	2.66	3.05	1.71	2.43	1.99	1.19	1.67	1.44	.91
	.050	.057		.009	.029	.028	.037	.042	.023	.033	.027	.016	.023	.020	.011
MgO	3.49	3.77		3.61	3.61	1.06	2.91	3.28	2.50	2.55	2.06	1.89	1.04	1.14	.82
	.087	.094		.090	.090	.026	.073	.082	.062	.064	.051	.047	.026	.028	.020
CaO	7.11	7.78	6.67	6.43	5.34	6.66	5.75	4.79	4.31	4.33	4.48	3.38	3.48	3.52	2.52
	.127	.138	.119	.114	.095	.115	.102	.085	.077	.077	.080	.060	.062	.063	.045
Na_2O	4.02	5.54	4.80	3.83	4.02	2.89	4.93	3.58	4.84	4.02	4.56	3.71	3.90	4.52	4.09
	.064		.077	.061	.064	.046	.079	.057	.078	.064	.073	.059	.063	.073	.066
K_2O	1.61		1.37	1.76	2.66	2.51	2.65	2.92	2.75	2.41	1.59	2.70	2.13	2.24	2.19
	.017		.014	.018	.028	.026	.028	.031	.029	.025	.016	.029	.022	.023	.023
P_2O_5	.25			.25		.22		.13		.17	.11	.09	.13		.13
SO_3										.05					
H_2O	.36	.06	.16	.47	.58	1.44	.15	.99	1.99	1.09	.55	2.07	.80	.33	2.92
	100.19	100.00		100.44	100.60	99.10	100.85	100.57	100.16	100.01	99.02	98.20	99.47	99.84	100.03

1. Pyroxene-andesite. N. W. foot of the Purgatorio. Pasto.
2. Olivine-pyroxene-andesite. Pasto.
3. Pyroxene-andesite. Cerro negro de Mayasquer.
4. Pyroxene-andesite. Azufral de Túquerres.
5. Hornblende-andesite. Peñon de Pitayó.
6. Hornblende-andesite. Loma de Ales.
7. Pyroxene-andesite. Lava of 1869. Pasto.
8. Hornblende-pyroxene-dacite, (with olivine and biotite) Cerro negro de Mayasquer.
9. Hornblende-pyroxene-dacite. Chiles.
10. Hornblende-dacite. (With biotite and pyroxene.) Llanos de las Mesas, Tajumbina.
11. Pyroxene-dacite. Cumbal.
12. Hornblende-pyroxene-dacite. Hondon, Chiles.
13. Hornblende-biotite-dacite. Azufral de Túquerres.
14. Hornblende-biotite-dacite. Azufral de Túquerres.
15. Hornblende-biotite-dacite. Loma de Ales.

TABLE II.

CHEMICAL ANALYSES OF VOLCANIC ROCKS OF THE ANDES.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	52.02	56.50	57.10	58.00	58.35	59.28	60.32	62.35	63.00	63.19	63.49	63.69	66.06	72.46	73.61
	.867	.941	.951	.966	.972	.988	1.005	1.039	1.050	1.050	1.058	1.061	1.101	1.207	1.227
TiO_2						tr				.18					
Al_2O_3	17.14	15.06	17.25	18.00	16.74	18.14	16.92	17.32	18.40	18.65	12.42	15.03	15.64	12.80	12.01
	.168	.147	.169	.176	.164	.177	.165	.169	.180	.183	.121	.147	.153	.125	.117
Fe_2O_3	7.94	13.52 (Fe₂O₃ and FeO)	10.75 (Fe₂O₃ and FeO)	3.72			5.88	4.51	3.96	4.01	6.41	2.51		2.32	2.27
	.049			.023			.036	.028	.024	.025	.040	.015		.014	.014
FeO	3.52			2.73	6.71	8.79	1.40			1.89	1.34	2.41	3.90		
	.048			.037	.093	.122	.019			.026	.018	.033	.054		
MnO	.85				.54	tr		.04	.10	.13	.85	.55	.71		
MgO	3.13	2.72	2.50	3.56	4.84	3.43	3.52	3.60	3.71	1.20	1.32	.80	2.57	tr	.20
	.078	.068	.062	.089	.121	.086	.088	.090	.093	.030	.033	.020	.064		.005
CaO	11.57	6.23	5.00	6.96	6.81	4.49	5.64	5.43	5.36	4.86	4.17	3.30	4.53	1.35	.89
	.206	.111	.089	.122	.121	.080	.100	.097	.095	.086	.074	.059	.080	.024	.015
Na_2O	2.38	4.55	5.12	4.36	4.69	4.26	3.83	4.29	4.22	3.69	4.90	6.54	4.00	4.48	4.34
	.038	.073	.082	.070	.075	.068	.061	.069	.068	.059	.079	.105	.064	.072	.070
K_2O	.60	1.35	2.10	2.12	1.18	1.85	2.42	3.13	2.36	1.95	1.78	2.46	2.36	4.11	3.82
	.006	.014	.022	.022	.012	.019	.025	.033	.025	.020	.019	.026	.025	.043	.040
P_2O_5	tr									.15	tr	tr			
H_2O	.28	.30	.25	.32	.31		.44	.13	.36	.07	2.88	2.23	.30	2.92	3.35
	99.45	100.23	100.07	99.77	100.17	100.24	100.37	100.80	101.47	100.07	99.56	99.52	100.09	100.44	100.53

1. Portañuela, Volcano Yate, Southern Chili.
2. Tunguragua, Ecuador.
3. Chimborazo, "
4. Chimborazo, "
5. Tunguragua, "
6. Carahuirazo, "
7. Chimborazo, "
8. Pichincha, "
9. Cachutafruto, Ecuador.
10. Tajumbina, Colombia.
11. Volcano Yate, Southern Chili.
12. Volcano Yate, "
13. Tunguragua, Ecuador.
14. Guamani, Tablon de Itulgache, Ecuador.
15. Oyacachi.

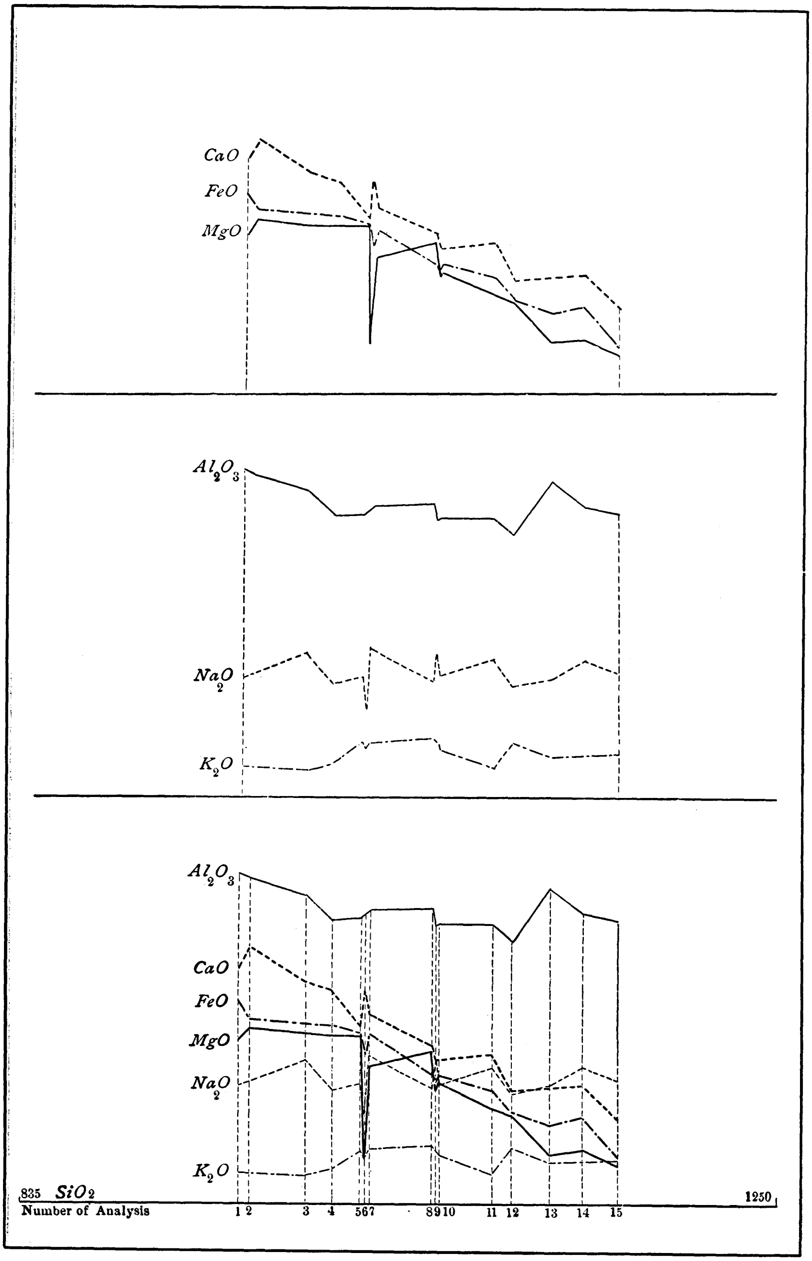

DIAGRAM I.—Molecular variations in lavas of Colombia.

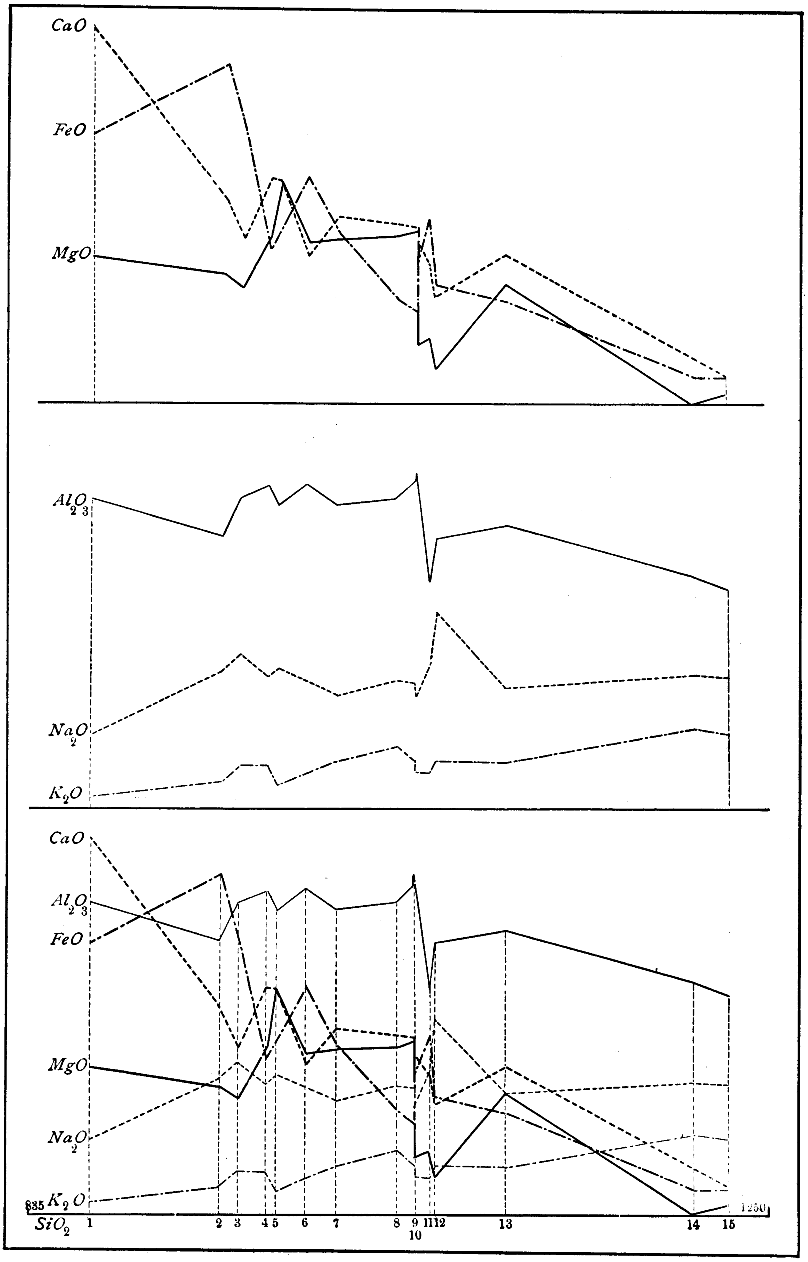

DIAGRAM 2.—Molecular variations in lavas of the Andes.

igneous rocks already cited. There is nearly the same relation between the alkalies and alumina, the soda being still more in excess of potash, and both increasing gradually toward the more silicious end of the series. The alumina maintains a high position, gradually decreasing. The lime, iron-oxide and magnesia decrease rapidly from the less silicious to the more silicious end of the series, and lie somewhat close together. In one instance there is a marked drop in the magnesia.

In Table II are given the analyses of lavas from the Andes south of Colombia, with one exception, as they have been recorded in Roth's tables of rock analyses. They present a somewhat wider range of silica percentages, from 52.02 to 73.61, but whether they have all been made from unaltered rocks is not known to the writer. An analyis of "obsidian" from Colombia is omitted, since it is extremely crude, giving 75 per cent. of silica and 3 per cent. of magnesia, with no lime. Diagram 2 expresses the molecular variations among the rocks included in this grouping. They have the same general nature as those just described, especially as to the alkalies and alumina; but the lime, iron-oxide and magnesia are more variable, which may represent the true condition of the case, or may be due to imperfect methods of analysis.

It is evident from these diagrams that the lavas of the Andes represent various phases of the differentiation of a magma which is chemically similar to that which has furnished the lavas of the Great Basin and extreme western Cordilleras in the United States, and that they belong to similar petrographical provinces.

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